Z65-11818

Z65-11818
(ACCESSION NUMBER)
20
(PAGES)
(NASA CR OR TMX OR AD NUMBER)
(THRU)
None
(CODE)
30
(CATEGORY)
FACILITY FORM 602

SINGLE COPY ONLY

Copy No. 5

SID 63-328

APOLLO IN-FLIGHT MAINTENANCE CONCEPT

Contract NAS9-150

18 April 1963

apollo

Z65·11818

Accession No. 20280

Copy No. 5

SID 63-328

APOLLO IN-FLIGHT MAINTENANCE CONCEPT

Contract NAS9-150

18 April 1963

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

FOREWORD

The In-Flight Maintenance (IFM) Concept is directed at the establishment of the basic philosophy of the Apollo in-flight maintenance program.

It has been developed to furnish guidelines for the Apollo Program and provides a firm basis for continued activity in the maintenance area. The general concept of in-flight maintenance described in this report may be applied to the lunar excursion module; however, concurrent with the development of the LEM program, interface coordination must be continued with the associate contractor to insure the effectiveness of the over-all spacecraft/IFM concept.

CONTENTS

INTRODUCTION

The inclusion of the three man crew on the Apollo allows for the provisioning of a maintenance capability. The Apollo (IFM) Program will provide a maximum maintenance capability with the realization that equipment reliability indicates minimum activity in this area. All aspects of maintenance and maintenance support are considered to assure the meeting of the IFM goals. These goals are defined as the development of a program that will most completely augment reliability, i.e., enhance the probability of mission success and crew safety. Studies which consider this augmented reliability versus the weight penalty imposed are being continuously conducted. Systems criticality is the primary factor in determining the extent of maintenance support to be provided for each system. An optimum reliability, through increased maintenance capability, is mandatory for those systems deemed most critical and may dictate the trade-off of maintenance support from those systems determined to be less critical.

This document outlines those maintenance activities that may be required during a typical Apollo spacecraft flight. It considers each mission phase as it affects maintenance and identifies the constraints imposed by the mission mode.

The maintenance functions are defined as inspection, adjustment, verification, servicing, fault isolation, replacement, and repair.

The maintenance support items required to accomplish effectively the maintenance tasks are listed.

A logic diagram and written description to illustrate the information, decision, and action aspects of the IFM program are provided. This conceptual approach will be utilized by the spacecraft crew in accomplishing IFM.

The primary means of implementing the in-flight maintenance capability is the in-flight test system, displays, spares, tools, technical data, training, and materials. This will support the crew member in the control position to make a maintenance related decision and take appropriate action. The primary system will furnish an independent detection and fault isolation capability to the spacecraft crew.

GOSS will be considered as a back-up or auxiliary system. It will have the capability of supporting the spacecraft crew in the determination of a maintenance decision or supporting a maintenance action. It will also furnish ground intelligence by making recommendations to the spacecraft-commander pertinent to the mission decision.

I. MISSION CONSIDERATIONS

INITIAL THRUST

The need to perform maintenance may arise at any point during the Apollo mission. However, the particular mission phase, because of work load, crew availability, or environmental conditions, may severely limit normal maintenance activities. A critical in-flight period on the Apollo equipment will be during the initial thrust. In this period of minimum maintenance activity by the crew, the spacecraft will be subjected to a high-g loading. During this phase, the crew safety system will be in control and will become the determining factor in making and supporting the mission decision, i.e., primary, alternate, or abort.

EARTH ORBIT

During earth orbit and prior to the translunar injection phase, a relatively high crew task loading can be anticipated. Continuation of navigational sightings and other activities preparatory to the translunar injection can interfere with and postpone the performance of maintenance due to simultaneous tasks occurring in the same location within the C/M.

Crew loading during this phase will be significantly influenced by the system verification capability provided. During the limited period of earth orbit, an effective verification system will provide a maintenance capability that may be the deciding factor between the continuation of the mission and mission abort.

TRANSLUNAR AND TRANSEARTH

The translunar and transearth coast periods provide the greatest opportunities for maintenance. Subsequent to the transposition of the LEM, and prior to lunar orbit injection, crew task loading will be relatively small. The same will apply from the transearth injection until prior to earth reentry.

LUNAR ORBIT

The entire lunar orbit phase is considered a peak load period. The division of the crew during lunar exploration imposes a very significant constraint upon maintenance. Any maintenance activity aboard the command module during this time will be a function of absolute necessity and may require the trade-off of other scheduled functions, such as those associated with guidance and control and communication.

The time periods prior to LEM separation, and after rendezvous, will be fully occupied with various system checks, scientific observation and scheduled tasks. The necessity for maintenance during these periods may also dictate a requirement to trade-off other type tasks.

EARTH REENTRY

The Earth reentry phase, like the ascent phase, will be a period of relatively limited maintenance.

II. CONSTRAINTS

WEIGHT

Weight is the most significant constraint on the Apollo in-flight maintenance program. It has an indirect effect by imposing restrictions on equipment design and a direct effect by limiting the quantity of on-board spares and other facilities of maintenance.

MISSION PHASE

During thrust periods, crew members will be restrained to their couches, which will limit maintenance to those functions that can be accomplished by manual switching consistent with existing g forces.

Since there is no established requirement for extravehicular activity for the Apollo in-flight mission, no analysis of crew activities related to this requirement is being conducted at this time.

During the period of lunar orbit and exploration, maintenance capability will be restricted by crew nonavailability.

CREW CONSTRAINTS

Crew constraints can be generally divided into several categories - those imposed by the adverse environment, those imposed by the hardware design, crew equipment and accessories, and those imposed by psychophysiological load capabilities.

EQUIPMENT ACCESSIBILITY

Physical placement of equipment within the command and service module will also limit, and may preclude, maintenance on some equipment. Prime consideration shall be given to the priority placement of critical equipment to ensure that an optimum maintenance capability is provided.

III. MAINTENANCE FUNCTIONS

MAINTENANCE REQUIREMENTS

Maintenance can arise from three basic causes: equipment failure, predictable degradation, and accidental damage. To predict accurately accidental damage to equipment is difficult; however, some equipment, because of precise design tolerances or physical placement within the spacecraft, may be considered more accident prone than other equipment. The probability of accidental damage will be considered in the over-all probability of failure determination.

MAINTENANCE CATEGORIES

Maintenance is separated into two categories, scheduled and corrective. Scheduled maintenance is performed at designated times, according to specific instructions, to maintain equipment and facilities in a satisfactory operating condition. Corrective maintenance is performed when equipment performance becomes unsatisfactory. Scheduled maintenance will be performed on equipment known to degrade as a result of time or usage, whereas corrective maintenance will be performed at unpredictable intervals as a function of necessity.

MAINTENANCE ACTIVITIES

Any maintenance activity required as a result of scheduled or corrective maintenance will be some combination of the following actions: fault isolation, replacement, repair, adjustment, servicing, calibration, verification, or inspection. Certain maintenance actions will be the result of scheduled verification and inspection; however, all maintenance activity will be concluded with verification and inspection to assure that equipment is operational and safe for continued operation.

MALFUNCTION DETECTION AND ISOLATION

Malfunction isolation and verification will be accomplished through the utilization of both an on-board capability and GOSS. Using the telemetry system, GOSS will monitor various points within the spacecraft systems. This not only provides a malfunction detection capability but also the ability to sense an impending malfunction. This is accomplished by the continuous monitoring of system signals and by sensing a degrading signal before it goes beyond the allowable operating parameters.

The crew will continuously monitor the display panels for gross system in-limits, out-of-limits indications. An out-of-limits signal directs the crew to the test-point panel. The utilization of the test-point panel and the on-board technical data will isolate malfunctions to the level of one to three plug-in assemblies. GOSS backup to the on-board checkout system is provided by the capability of telemetering the test-point signals to GOSS. The composite system furnishes a maximized malfunction detection and isolation capability. It also provides a limited transfer capability during periods of peak crew loading when maintenance efforts will be limited.

Fault detection and isolation utilizing the displays, IFTS, and GOSS have been discussed. However, situations may arise for which no detection capability is provided. Such conditions may be detected by the crew through sensory means. These conditions can be transmitted through GOSS to ground operations for analysis. Ground analyses and recommendations will, in turn, be transmitted to the spacecraft crew for appropriate action.

REPAIR FUNCTION

It can be generally stated that the majority of corrective maintenance will be directed at the electronics systems. This maintenance will, in most cases, be limited to the isolation of malfunctions and the replacement of replaceable units. The limitation of maintenance to replaceable units does not preclude the possibility of crew discretion-type fixes where damage or malfunction causes are readily discernible.

The repair function will also include the adjustments required to return a system to normal operation.

IV. MAINTENANCE SUPPORT

SPARES

The spares determination poses one of the most stringent analytical requirements of the Apollo Program. The identification of on-board spares will be predicated on system criticality, probability of failure, and weight restriction. Spares will only be provided for those items that are accessible and repairable.

TOOLS

The selection of the in-flight maintenance tools will be based upon their capability to effectively accomplish the required task. The possibility of providing a dual purpose capability and minimizing redundancy also influences the selection of this equipment. Other tool and equipment considerations are:

1. Minimum weight
2. Compatibility with space suit
3. Operability in a weightless environment to 1-g environment
4. Operability in a low-pressure ambient environment
5. Operability in an extreme temperature environment
6. Accommodation for carrying in an in-flight maintenance vest
7. Ready accessibility
8. Efficient psychomotor utilization
9. Operability in a 100 percent oxygen environment

TECHNICAL DATA

Technical data in support of the maintenance functions will be provided in a comprehensive and compact form. It will be aligned to the in-flight test system and provide data relevant to the on-board maintenance capability.

EQUIPMENT

The equipment to support maintenance consists of the in-flight test system (primary) and GOSS (auxiliary). A general description of the functions of these systems is found in the first two paragraphs of Fault Isolation and Verification.

MATERIAL

The material required in support of maintenance will be identified when equipment servicing and repair requirements are clearly defined.

TRAINING

To implement in-flight maintenance effectively, a comprehensive crew training program will be established and conducted. Training will emcompass these areas: detection of system degradation, recognition of marginal conditions for a particular mission phase, failure analyses, decision factors for corrective action, corrective action procedures, periodic servicing, and systems management. Formal training together with the use of systems, mission simulators, and a part-task trainer will be utilized to insure proficiency.

V. MAINTENANCE EVENTS LOGIC

A general logic to cover all possible in-flight maintenance situations and conditions is presented in Figure 1. An examination of this logic reveals that along all the many possible branch paths, the three-step pattern of information to crew, decision by crew, and action by crew, repeats itself.

LOGIC EXPLANATION

The following is a step-by-step explanation of the logic shown in Figure 1. The explanations are keyed to the diagram by the reference numbers following each heading. The explanation begins with the "Mission Decision" at the bottom of the logic diagram. It is this mission decision point to which all the other steps lead. Ideally, the decision will be to remain in the "Primary Mission" mode until the mission is completed. If a failure occurs, a sequence of in-flight maintenance events is initiated that will ultimately lead back to the mission decision. If other failures occur, the cycle repeats itself along one of the branch paths, always leading back to the mission decision point.

Mission Decision (A). The crew is, in effect, continuously making the mission decision. This decision results in one of the three possible mission actions: continuing the primary mission, substituting an alternate mission, or initiating an abort procedure. Taking no action is equivalent to deciding to continue in the present action status.

Primary Mission (B). This is the normal condition of the spacecraft and crew in which both are functioning satisfactorily for continuance of the primary mission.

Alternate Mission (C). This is a degraded condition of spacecraft and/or crew in which one or both are not functioning satisfactorily for the continuance of the primary mission, requiring that an alternate mission be chosen. Examples of such a situation would be the substitution of a circumlunar mission for a lunar landing mission, or the substitution of an earth orbital mission for a circumlunar mission.

Abort Mission (D). This is a further degraded condition of the spacecraft and/or crew in which the performance of one or both has been reduced to the point that the only consideration is the safe return of the crew. At many points, the abort mission will be the same as an alternate mission, i. e., during the latter portions of the translunar coast phase, the shortest way back to earth is to continue around the moon on the circumlunar route.

Occurrence of Failure (E). At any time during the mission a failure may occur. In the event it does, a sequence of IFM events is initiated. Normally, this sequence follows a three-step pattern in which, first, there is a presentation of information to the crew concerning the failure and the existing conditions under which it occurred; second, a decision by the crew as to what should be done; and third, an action by the crew appropriate to the decision.

Indication (F). Some situations which may occur are of such nature that they will be sensed directly by the crew, i. e., a fire, the bursting of a pressure vessel in the command module, etc. Other abnormalities will be indicated to the crew by an instrumented display to insure their timely sensing.

Critical Component (G). Upon indications that a malfunction or failure has occurred, the crew must decide, considering the conditions that exist at the time, the degree of criticality. If the malfunction or failure is considered to be noncritical, the crew may switch to an alternate mode. If the alternate mode is not available, the crew will proceed directly to the mission decision where it must be decided if this failure has caused a serious enough degradation to require the selection of an alternate or abort mission. If the failure is considered to be critical, the crew may again switch to an alternate or redundant mode, if this is desirable, and proceed with an appropriate in-flight maintenance action.

Alternate Mode (H). In some cases there will be alternate modes available for noncritical components as an indirect result of the redundant and alternate modes provided for the critical components.

Redundant or Alternate Mode (J). Depending upon the existing conditions and the type of failure involved, it may be necessary to switch to a redundant or alternate mode. This action may be automatic in which case it is merely confirmed by the crew before proceeding.

IFM Procedures and Technical Data (K). In-flight maintenance corrective procedures and technical data shall be utilized by the crew as an aid in making decisions and will outline necessary steps required in the performance of a given maintenance task.

Maintenance Possibility Decision (L). Having decided that the failure is of a critical nature, the crew must decide, again considering the conditions existing at the time, the possibility and practicality of initiating a maintenance procedure. If it is decided that it is not possible or practical to attempt in-flight maintenance, the crew must again make the mission decision as to whether this failure has caused a degradation serious enough to require the substitution of an alternate mission or an abort procedure. If maintenance appears possible, the following sequence of events (2. 7. 12 to 2. 7. 19) is executed.

Spares Stock (M). Available at all times to aid the crew in making decisions will be information as to the stock of spares on hand.

Spares Availability (N). Based upon the number of spares on hand, if any, the system involved, and the rate of spares usage, the crew must make a decision as to whether to initiate a component replacement action or a component repair action.

Replace (O). If it is decided to make a component replacement, a spare is taken from the stock and installed in accordance with the in-flight maintenance procedures and technical data.

Repair (P). If after determining that no spares are available or it is otherwise desirable to attempt the repair of a component, this action may be initiated in accordance with the in-flight maintenance procedures and technical data.

Verification (Q). Upon completion of the replacement or repair action, there must be a verification to establish that the failure has actually been eliminated.

Successful Replacement or Repair (R). If the replacement or repair operation was successful, then the crew may take steps to return to the primary mode. If the operation was not successful, the situation returns to the point of deciding that the failed component is critical and proceeding again from there.

Primary Mode (S). After having successfully completed the replacement or repair operations, it will normally be desirable to return to the primary mode.

Monitoring (T). After having successfully completed an in-flight maintenance operation, the crew will return to the normal condition of monitoring displays and making a mission decision.

APPLICATION OF MAINTENANCE EVENTS LOGIC

This event logic provides a feasible framework upon which the details of an IFM plan may be organized. For each information-to-crew event, it is necessary to analyze and evaluate the methods by which the information was conveyed to the crew. Similarly, for each decision-by-crew event, a set of criteria must be established. Finally, for each possible action-by-crew event, procedures and technical data must be provided. Such details must be developed for each failure that has a significant probability of occurrence as determined by systems analysis.

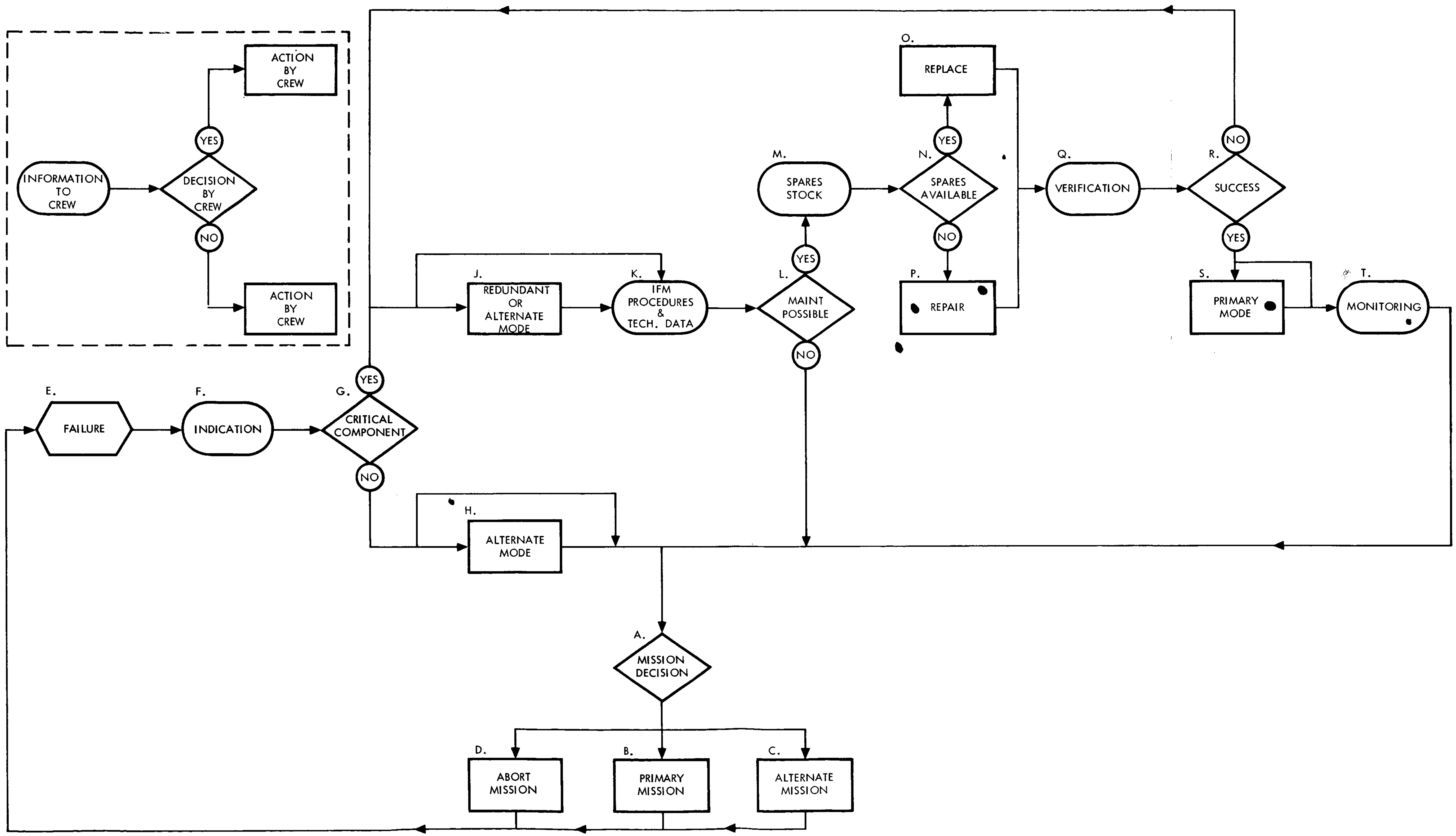

Figure 1. IFM Logic Diagram

VI. CONCLUSION

This document establishes the requirements for an effective in-flight maintenance program. It defines the maintenance functions and support categories insofar as the state of equipment design will allow.

The maintenance function, irrespective of where it is accomplished, is of necessity the same. The basic difference is in the constraints and environmental conditions under which the maintenance is performed.

The in-flight maintenance program will be predicated on an ability to minimize the effects of constraints and environmental conditions and on the logical design of equipment maintainability within these conditions.

It will further depend on an ability to predict analytically the probability of failure and the provisioning of redundancies, spares, and material in support of the required maintenance actions.

The end product will be the sum of the knowledge and efforts of all the sciences in the provisioning of a complete and workable in-flight maintenance program.

GLOSSARY

ADJUSTMENT	A means by which parts, as of a machine or device, are adjusted to one another, primarily to attain an operating standard peculiar to the unit in use and governed to some degree by associated equipment.
FAILURE	A failure is an occurrence, either catastrophic or gradual deterioration, which causes the performance of the equipment to deviate from specified limits, as detailed in the equipment specifications. It is a condition which requires maintenance to return the equipment to satisfactory operation.
FAULT ISOLATION	The act of isolating a defect or malfunction in a system or component by using a predetermined method, e.g., switching, using test points, or replacing part for part.
IN-FLIGHT MAINTENANCE	The use of available maintenance equipment, spares, and technical information, in accordance with procedures established in the In-Flight Maintenance Plan to augment the probability of mission success and maximize crew safety.
INSPECTION	The process of testing, measuring, examining, gaging, or otherwise comparing a product with the applicable requirements.
MAINTENANCE	All actions necessary for the retaining of material in, or restoring it to, a serviceable condition. Its phases include servicing, repair, modification, modernization, overhaul, rebuild, test, reclamation, inspection, condition determination.
PREDICTABLE DEGRADATION	The ability to predict the degree or amount of degradation within a system or unit by mathematical calculations and/or time proven test results.
REPAIR	The restoration of a system/equipment to a satisfactory operating condition after malfunction, damage, or deterioration.

REPLACEMENT	The substituting of one unit for another identical unit (i.e., the substitution of a properly functioning unit for a malfunctioning unit).
SERVICING	Work carried out at regular intervals, or under a recognized system, to keep equipment operable. It includes cleaning, inspecting, lubricating, adjusting, charging, and changing filters, desiccators, etc.
VERIFICATION	The process of substantiating the accuracy and completeness of an operation by actually performing an operational-test in accordance with the technical data.